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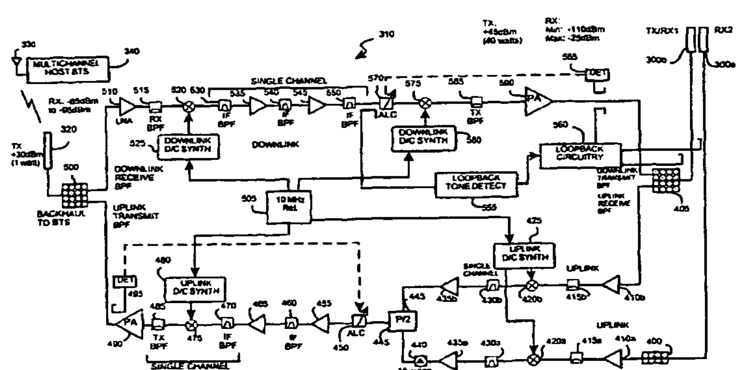
(54) Title: METHOD AND APPARATUS EMPLOYING DELAY COMBINING FOR RECEIVE DIVERSITY IN A WIRELESS SYSTEM REPEATER



(57) Abstract: An approach to extending TDMA system coverage is disclosed wherein in-band translator components are located in the center of remote cells which would normally contain a base transceiver system (BTS). The in-band translators employ delay combining to preserve receive diversity, in order to mitigate deep Rayleigh fades. Delay combining produces the diversity effect by introducing a small time delay between the two spatially separate receive paths which serves to maximize the quality of received signals. The same carrier signal is received by two uplink antennas located at least 8 wavelengths apart (over 4 feet apart at 1900 MHz). Both receive paths are broadly filtered (over the entire licensed RF receive band), low-noise amplified, downconverted to an IF, and narrowband filtered to a single carrier. One path is then delayed by up to 16 μsec and then combines with the other path. The composite is then sent through a fast automatic level control (ALC) and brought to a constant level. This signal is then upconverted to the desired uplink backhaul RF frequency and transmitted at high power to the serving BTS via a directional antenna. Adaptive delay equalization processing in the BTS removes the delay spread so that the combined signals can be separated and demodulated as one signal. The combined signal has similar signal-to-noise performance as a switching diversity method without requiring switching hardware or slot-by-slot timing.

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METHOD AND APPARATUS EMPLOYING DELAY COMBINING FOR RECEIVE DIVERSITY IN A WIRELESS SYSTEM REPEATER

This invention relates generally to wireless communication systems. More specifically, this invention relates to remote repeaters in wireless communication systems and in particular to a method and apparatus for employing delay combining for receive diversity in a wireless system repeater.

BACKGROUND OF THE INVENTION

The demand for wireless communication services, such as Global System for Mobile Communications (GSM), Cellular Mobile Telephone (CMT), Personal Communication Services (PCS) and the like, typically requires the operators of such systems to serve an increasing number of users. As a result, a type of base station equipment known as a multicarrier broadband Base Transceiver System (BTS) has been developed which is intended to serve a large number of active mobile stations in each cell. Such broadband BTS equipment can typically service ninety-six simultaneously active mobile stations, at a significant cost per channel.

When coupled with efficient frequency reuse schemes, such as that described in U.S. patent No. 5,649,292 entitled "A Method For Obtaining Times One Frequency Reuse in Communication Systems" issued to John R. Doner and assigned to AirNet Communications Corporation, who is the assignee of the present application, maximum efficiency in densely populated urban environments is obtained. According to that arrangement, each cell is split into six radial sectors and frequencies are assigned to the sectors in such a manner as to provide the ability to reuse each available frequency in every third cell. Although this frequency reuse scheme is highly efficient, it requires at least two complete sets of multicarrier transceiver equipment such as in the form of a broadband base transceiver system (BTS) to be located in each cell. Such a configuration results in dramatically increased hardware installation costs for each cell.

While this equipment is cost effective to deploy when a large number of active mobile stations is expected in each cell, it is not particularly cost effective in most other situations. For example, during an initial system build out phase, a service provider does not actually need to use large numbers of radio channels. It is therefore typically not possible to justify the cost of deploying complex multicarrier broadband transceiver system equipment based only upon the initial number of subscribers. As a result, the investment in broadband multicarrier radio equipment may not be justified until such time as the number of subscribers increases to a point where the channels are busy most of the time. Furthermore, many areas exist where the need for wireless communication systems is considerable, but where signal traffic can be expected to remain low indefinitely (such as in rural freeway locations or large commercial/industrial parks). Because only a few cells at high expected traffic demand locations (such as in a downtown urban location or a freeway intersection) will justify the initial expense of building out a network of high capacity broadband transceiver systems, the service provider is faced with a dilemma. He can build-out the system with less expensive narrowband equipment initially, to provide some level of coverage, and then upgrade to the more efficient equipment as the number of subscribers rapidly increases in the service area. However, the initial investment in narrowband equipment is then lost. Alternatively, a larger up-front investment can be made to deploy the high capacity equipment at the beginning so that, once demand increases, the users of the system can be accommodated without receiving busy signals and the like. But this has the disadvantage of requiring a larger up-front investment.

Further complicating the situation is the fact that, regardless of the device used to extend the range of cell sites, any device with a single uplink receive antenna will suffer from severe Rayleigh fading, or destructive wave interference, of widely varying magnitude, due to the wave

cancellation effects of reflected and retransmitted signals. As can be readily understood, the likelihood of Rayleigh fading or multipath distortion increases proportionally to an increase in the distance between the mobile unit and the base station.

The use of two spatially diverse antennas for the uplink signal from the mobile station will provide diversity gain and mitigate deep fades since fades will generally occur at a different time for one antenna relative to a spatially separated second antenna. The use of multiple antennas can accompany increased frequency usage in the "backhaul" frequency band employed for communication between the BTS and the cell range-extending remote base station device. However, the use of selective diversity will mitigate this effect.

For GSM-1900 (formerly PCS-1900) and GSM-1800 (formerly DCS-1800), the uplink signal strength from a mobile station can vary by as much as 80 dB, typically from -25 dBm to below -105 dBm. For GSM-900, the uplink signal strength can vary by as much as 92 dB, typically from -13 dBm to below -105 dBm. This large range of signal strength necessarily restricts the distance of successful propagation of the backhaul signal from the range extending remote base station device to the BTS.

Some have proposed various techniques for expanding the service area of a master cell site. For example, the HPT Cell Site Expander product manufactured by 3dbm, Inc., of Camarillo, California, consists of a base station translator which samples downlink signal traffic and translates it to a selected offset frequency. The offset carrier is transmitted to an expansion cell site via directional antennas. At the expansion cell site, the carrier is translated back to the original cellular channel and transmitted throughout the expansion cell site coverage area such as via an omnidirectional antenna. In the uplink direction, a cellular signal received by the expansion cell site from a mobile unit is translated and then transmitted back to the base station translator, which in turn translates the signal back to its original carrier frequency.

However, such a device is designed only for use with analog-type cellular systems. A specific problem is encountered when attempting to extend the service area of a base station that uses Time Division Multiple Access (TDMA) signaling. Such a system makes use of a technique in which multiple voice or data channels are provided by dividing the access to each radio carrier frequency into carefully synchronized time slots. In order to demodulate a TDMA signal properly at the base station, a timing advance must be taken into consideration for each radio pulse received from the mobile stations. The timing advance serves to compensate for the differences in signal propagation time since the distance to the base station is different for each mobile station.

A TDMA signal transmitted in the uplink direction must therefore arrive at the Base Transceiver System with proper time alignment. If this is not the case, the signal pulses from the various mobile stations will collide, and it will not be possible for the Base Transceiver System to demodulate the signals properly. As such, it has in most instances been necessary to limit the nominal radius of a TDMA cell so that proper time alignment may be maintained.

An approach to extending the radius of a TDMA cell was disclosed in U.S. Patent 5,544,171, issued to Goedecker and assigned to Alcatel N.V. This technique uses a fixed Base Transceiver System (BTS) that includes both a standard TDMA radio receiver and an additional auxiliary TDMA receiver. The auxiliary TDMA receiver receives and compensates the TDMA radio pulses from mobile stations located outside of the nominal cell radius. In this manner, interference between the TDMA signals received from a mobile station located outside of the nominal cell radius and a mobile station located within the nominal radius is avoided.

The Goedecker technique has been expanded in U.S. Patent No. 5,825,764, issued to Rudolph and also assigned to Alcatel N.V. Rudolph discloses a method of extending the range of a cell served by a GSM-type base transceiver station in concentric rings of 35 km width by co-locating an additional

pair of standard TDMA receiver and auxiliary TDMA receiver for each successive ring, thereby theoretically permitting the range of a single cell to be extended continuously in any direction.

Unfortunately, the Goedecker technique is intended for use where both radio transceivers can be located entirely within the base station site. This permits the timing signals for the auxiliary TDMA receiver to be directly connected to the timing signals for the standard TDMA receiver. Thus, it would not be possible to directly apply the Goedecker technique to a remote repeater or translator arrangement, where the auxiliary TDMA receiver would have to be located many miles away from the base station site and such timing signal connection would not be possible. Furthermore, the Rudolph technique requires a third auxiliary receiver located at the site of each range extender installation, to receive incoming calls from the inner cell area. Therefore, in addition to the drawbacks of the Goedecker technique, Rudolph also includes higher hardware installation requirements to achieve cell extension. In fact, the Rudolph disclosure admits that a direct application of the arrangement to n concentric cells would require n times n receivers.

Furthermore, while the HPT, Goedecker, and Rudolph designs can be used to extend the radius of a single cell, they do not appear to suggest how to synchronize TDMA signals received from multiple mobile stations located in multiple cells simultaneously, and in the cases of HPT and Goedecker, they do not suggest any form of random access control channel processing of initial uplink transmissions from mobile stations.

U.S. Patent No. 5,615,215, issued to Utting *et al.* describes another cell extending strategy that requires multiple receivers per cell.

Other techniques for extending the service area of a given cell include, for example, U.S. Patent 4,727,490 issued to Kawano *et al.* and assigned to Mitsubishi Denki Kabushiki Kaisha. Kawano discloses a mobile telephone system in which a

number of repeater stations are installed at the boundary points of hexagonally shaped cells. The repeaters define a small or minor array which is, in effect, superimposed on a major array of conventional base stations installed at the center of the cells. With this arrangement, any signals received in so-called minor service areas by the repeaters are relayed to the nearest base station.

Another technique for cell service range extension was disclosed in U.S. Patent 5,152,002 issued to Leslie *et al.*, and assigned to Orion Industries, Inc., wherein the coverage of a cell is extended by including a number of so-called "boosters" arranged in a serial chain. As a mobile station moves along an elongated area of coverage, it is automatically picked up by an approaching booster and dropped by a receding booster. These boosters, or translators, use highly directive antennas to communicate with one another and thus ultimately via the serial chain with the controlling central site. The boosters may either be used in the mode where the boosted signal is transmitted at the same frequency as it is received or in a mode where the incoming signal is retransmitted at a different translated frequency.

Unfortunately, each of these techniques have their difficulties. In the Kawano method, which uses an array of repeaters co-located with the primary cell sites, the implementation of diversity receivers becomes a problem. Specifically, certain types of cellular communication systems, particularly those that use digital forms of modulation, are susceptible to multi-path fading and other distortion. It is imperative in such systems to deploy diversity antennas at each cell site. This repeater array scheme of Kawano makes implementation of diversity antennas extremely difficult, since each repeater simply forwards its received signal to the base station, and diversity information as represented by the phase of the signal received at the repeater, is thus lost.

The scheme disclosed by Leslie is appropriate for situations where the boosters are intended to be arranged in a straight line, such as along a highway, a tunnel, a narrow

depression in the terrain such as a ravine or adjacent a riverbed. However, there is no teaching of how to deploy the boosters efficiently in a two-dimensional grid, or to share the available translated frequencies as must be done if the advantages of cell site extension are to be obtained throughout an entire service region, such as a large city.

With respect to Rayleigh fading in cell extending translating repeaters, it is known in the art to employ switched diversity selection to combat deep fades of up to 30 dB associated with multipath in the uplink. Switched diversity techniques typically include two spatially separated antennas with an electronic selection mechanism to choose the strongest signal of the two paths. Multipath fading will normally occur at each separate receive antenna at a different time due to their spatial separation, so automatically selecting the stronger of the two signals mitigates the deep fades that would be intermittently or continually present if only one antenna were employed.

To achieve switched diversity in a translating repeater in a GSM-based cellular communications system, such as GSM-900, GSM-1900, or GSM-1800, the diversity switching must be conducted independently for each of the 8 time slots on a given RF carrier. To reduce bit errors, the actual switch must be made during the 3-bit guard period at the beginning of each signal burst, and not during the active 147 bits of data. This carefully timed switching can be accomplished by using rapid power detection of both receive signal paths while delaying the received signals through bulk delay elements and making the switch during the guard period. However, this technique requires careful timing and additional hardware in order to engage. A co-pending United States patent application entitled "Method and Apparatus Employing Delay Elements In Multiple Diversity Paths of a Wireless System Repeater Translator to Allow for Selective Diversity and Automatic Level Control in a Time-Division Multiple Access System" filed November 24, 1998 and which is assigned to AirNet Communications Corporation, the assignee of this

application, describes the details of employing bulk delay elements to achieve diversity selection in wireless in-band translating repeaters.

An alternative to switched diversity is frequency diversity, wherein two separate backhaul signals-one for each antenna-are transmitted on separate frequencies from the translating repeater to the multichannel host BTS. This technique has the disadvantage of being extremely hardware intensive, as nearly twice as much hardware is required to transmit the two separate backhaul signals. Also, twice as many backhaul frequencies are required in the uplink. Furthermore, the multichannel host BTS is required to receive both frequencies and make the diversity selection. This creates the need for the careful timing and additional hardware as earlier described, as well as increasing the number of costly receivers required for the multichannel host BTS.

DESCRIPTION OF THE INVENTION

Objects of the Invention

It is an object of this invention to extend the available range in a cellular communication system beyond that which is normally available with Time Division Multiple Access (TDMA) air interfaces.

Another object is to provide for spatial diversity to eliminate multi-path Rayleigh fading.

A further object is to employ delay combining to produce signal-to-noise ratio performance similar to that achieved with switching diversity methods.

It is yet another object of this invention to employ delay combining to achieve diversity selection while avoiding the requirement of hardware associated with switching diversity selection and frequency diversity selection techniques.

Summary of the Invention

Briefly, the invention is based on an architecture for a

wireless communication system in which cells are grouped into clusters. A host cell location is identified within each cluster and a multicarrier broadband Base Transceiver System (BTS) is located at or near the host cell site.

Rather than deploy a complete suite of base station equipment at each remaining cell in the cluster, translating radio transceivers are located in the remote cells. These translating radio transceivers operate in-band, that is, within the frequencies assigned to the service provider.

The in-band translators operate in both an uplink and downlink direction. That is, uplink signals transmitted by a mobile station located in a remote cell are received at the in-band translator, translated to a different carrier frequency, and then transmitted to the host BTS. Likewise, downlink signals transmitted by the host BTS are first received by the in-band translator, translated to a different carrier frequency, and then repeated out to the mobile stations at high power.

The host BTS measures a time delay for each in-band translator channel during a calibration mode. This is accomplished by setting the inband translator to a loop-back mode whereby the high-power translated downlink signal received from the host BTS is coupled and mixed via frequency translation back to the BTS via the uplink transmit path. A timing test signal in the form of, for example, a random access control channel (RACCH) burst is then transmitted by the host BTS such as would normally be sent by a mobile station. The RACCH burst is received by the in-band translator and looped back to the host BTS. The host BTS then demodulates the looped back signal, and measures the elapsed time interval between the transmission and reception of the loop-back signal at the host BTS. A resulting round-trip time-of-arrival delay estimate as measured in the downlink and uplink path is then calculated and used by the host BTS to compensate for time alignments to be made in the time slots for the downlink and uplink signals during normal operation.

As a result, the time delay limitation on the backhaul

distance of the cell site normally associated with Time Division Multiple Access protocols is avoided. Indeed the range of such a system is limited only by the expected attenuation in the radio link. The time delay limitation applies only to the distance of the mobile unit from the range extending repeater-translator remote base station.

In accordance with the invention, the in-band translator introduces a small time delay between the two spatially separate receive paths, which serves to maximize the quality of the received signals. Both signals are broadly filtered (over the entire licensed radio frequency receive band), low-noise amplified, downconverted to an intermediate frequency, and narrowband filtered to a single carrier. One of the signal paths is then delayed by up to 16 μsec and combined with the signal from the other path. The composite signal is then sent through a fast automatic level control (ALC) and brought to a constant level. This signal is then upconverted to the desired uplink backhaul frequency and transmitted at high power via a directional antenna to the serving base transceiver station.

The delay combining diversity of the present invention eliminates the need to detect signal strength of both uplink paths and switch to the stronger signal on a burst-by-burst basis with precise timing, as in prior art switched diversity systems. In the preferred embodiment of the present invention, delay combining diversity takes advantage of the "adaptive delay equalization" inherent in base station processing in GSM-based systems such as GSM-1900, GSM-1800, and GSM-900 systems. The delay equalization processing removes up to 16 μsec of delay spread (4.33 bits at 1900 MHz) from a received signal.

As a result, the in-band translator compensates for deep Rayleigh fades occurring in uplink signals received from randomly positioned mobile stations, by allowing the stronger signal to dominate when the spatially separate receive path signals are separated and demodulated as one signal. The combined signal has a similar signal-to-noise ratio as a

signal selected through a switching diversity method, yet no switching hardware or slot-by-slot timing is required.

Brief Description Of The Drawings

For a more complete understanding of the invention and its novel advantages and features, reference should be made to the accompanying drawings in which:

Fig. 1 is a view of a cell site cluster showing how a host Base Transceiver System (BTS), in-band translators, and mobile stations are deployed according to the invention;

Fig. 2 is a block diagram of the components of the system;

Fig. 3 is a detailed block diagram of a translator embodying the present invention in a PCS-1900 system.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Fig. 1 illustrates a wireless communication system **100** such as a Cellular Mobile Telephone, Personal Communication System (PCS), or similar system in which employing delay diversity combining in the uplink signal paths of a wireless system repeater translator enables proper demodulation at the BTS of signals received from in-band frequency translating-repeater remote base stations deployed in peripheral cells.

The system **100** provides voice and or data communication between mobile stations 19 and a Public Switched Telephone Network (PSTN) via radio signals. In the particular embodiment of the invention being described, the radio signaling protocol, or "air interface," uses a Time Division Multiple Access (TDMA) technique such as the GSM-1900 (formerly PCS-1900) standard promulgated by the Telecommunications Industry Association (TIA) in the United States which adopts all relevant aspects of the Global System for Mobile Communication (GSM) standard developed by the Groupe Special Mobile, and promulgated in Europe and elsewhere by the European Telecommunication Standards Institute (ETSI).

The in-band translators (IBTs) **120-1, 120-2, . . . , 120-**

n (also referred to herein as the "remote base stations") are each located in what is normally to be approximately the center of a respective cell site **220-1, 220-2, . . . , 220-n** among a group or cluster **240** of cells. The in-band translators **120** receive radio signals from the mobile stations **200** located in their respective cells **220** and forward these signals to the associated multichannel host broadband Base Transceiver System (BTS) **150**. Likewise, radio signals originating at the host BTS **150** are forwarded by the translators **120** to the mobile stations **200**. As a result, the signals associated with all of the mobile stations **200** located within the cluster **240** of cells **220-1, . . . , 220-n** are thereby processed at the host BTS **150**.

The in-band translators **120** are configured as "base stations" in the sense that they are each associated with a particular cell **220** and in that they each receive and transmit multiple signals from and to the mobile stations **200**. However, the in-band translators **120** do not perform demodulation and modulation functions as does a conventional base station. Rather, they serve only to perform in-band frequency-translation and amplification of signals received from the mobile stations **200** and then direct such signals on a different frequency to the multichannel host BTS **150**. The in-band translators **120** also perform the inverse function, to translate the frequency of signals received from the host BTS **150** and then direct them to the mobile stations **200**.

Turning attention now to Fig. 2, the system **100** more particularly includes pairs of translator omni-directional antennas **300-1-1a** and **300-1-1b, . . , 300-1-12a** and **300-1-12b,. . . , 300-n-1a** and **300-n-1b, . . . , 300-n-12a** and **300-n-12b** (collectively, the omni-directional antennas **300**). The antenna pairs are connected to in-band translator base stations (wireless translating range extenders) **310-1-1, . . .**

, **310-1-12, . . ., 310-n-1, . . . , 310-n-12,** translator base station directional antennas (backhaul antennas) **320-1-1, . . . , 320-1-12, . . ., 320-n-1, . . . , 320-n-12,** host base station omni-directional antennas **330-1, . . . , 330-n,** multichannel host Base Transceiver Systems (BTS) **340-1, . . . , 340-n,** one or more base station controllers **350,** a mobile switching center **360,** and mobile stations **370-1, 370-2.**

The host BTSs **340-1, . . . , 340-n** are responsible for demodulating radio signals as well as for connecting such signals to a landline network through one or more base station controllers **350** and the mobile switching center **360.** The landline network is typically a Public Switched Telephone Network (PSTN) or an Integrated Digital Service Network (ISDN), but it may also be a Public Land Mobile Network (PLMN), or a Packet Switched Data Network (PSDN). In the reverse direction, the host BTSs **340-1, . . . , 340-n** also modulate signals received from the landline network through the mobile switching center **360** to format them for transmission over the air through the in-band translators **310.**

Regarding the arrangement of the multichannel host BTS **340-1 ... 340-n,** each particular host BTS, e.g. multichannel host BTS **340-1** serves the multiple in-band translators associated with a given cluster **240** of cells **220,** e.g. in-band translators **310-1-1, . . . , 310-1-12.** In the embodiment disclosed by Fig. 2, each multichannel host BTS **340-1** and **340-n** is depicted as serving its maximum number of twelve in-band translators **310-1-1, . . . 310-1-12,** and **310-n-1, . . . , 310-n-12,** respectively.

The Base Station Controller (BSC) **350,** of which there may be more than one, has a number of functions. The primary function is to manage the logical connections made between mobile stations **370** and the landline network. In order to do so, the Base Station Controller **350** assigns transmit and

receive radio carrier frequencies to each individual mobile station **370**, in-band translator **310**, and host BTS **340**. Typically, there may be five to twenty multichannel host BTSs **340-1**, . . . , **340-n** serviced by a single Base Station Controller **350**.

United States patent number 5,537,435 entitled "Transceiver Apparatus Employing Wideband FFT Channelizer with Output Sample Timing Adjustment and Inverse FFT Combiner for a Multichannel Communication Network" issued July 16, 1996 and which is assigned to AirNet Communications Corporation, the assignee of this application, describes the details of several embodiments of the multichannel BTS **340**.

Fig. 3 is a detailed block diagram of the components of an exemplary in-band translator **310** employing the delay combining of the present invention. The translator **310** shifts the carrier frequency of the signals received from one link (e.g. ground, for communication with a mobile station), to the appropriate transmit frequency for the other link (e.g. backhaul, for communication with a multichannel base station). The illustrated translator **310** also acts as a type of spatial diversity converter for the uplink direction as has already been mentioned. In particular, because no signal uses a radio frequency which is in use in the same cell for more than one type of link, the translator **310** may take advantage of spatial diversity reception on the backhaul link and use delay combining diversity to maintain the information over the backhaul link.

The translator **310** consists of translated signals received from the mobile link by the pair of spatially diverse omnidirectional antennas, **300a** and **300b**. In the preferred embodiment shown in Fig. 3, omnidirectional antenna **300a** is receive only, while omnidirectional antenna **300b** is transmit/receive. Further, in the preferred embodiment of the present invention, antennas **300a** and **300b** are spaced at least 8 wavelengths apart, or more than 4 feet at 1900 MHz, using

the GSM-1900 standard of the current embodiment. A separate receive filter **400** and the receive portion of a duplexer **405** provide a portion of the receive signal to a pair of intermediate frequency (IF) signal processing chains consisting of a pair of low noise amplifiers (LNA) **410a, 410b,** receiver band-pass filter **415a, 415b** that limits the received energy to the desired RF MHz band such as the GSM 1900 band allocated from 1850 to 1910 MHz. The mixers **420a, 420b** which are driven by a first synthesizer, uplink downconvert synthesizer **425,** convert the received signals to an intermediate frequency, and IF band pass filters **430a, 430b,** limit the IF signal to a single channel. The mixers **420a, 420b,** IF band pass filters **430a, 430b,** and intermediate frequency amplifiers **435a, 435b,** comprise an IF stage.

Uplink downconvert synthesizer **425** and other synthesizers in the translator **310** share a common 10 MHz reference **505.** The IF center frequency is typically chosen to be approximately 100 MHz, with a 300 KHz channel bandwidth associated with the IF bandpass filters.

In accordance with the principles of the invention, one of the signal paths is delayed by up to 16 μsec, before being combined with the second signal path. In the present embodiment of the invention, the signal path originating at receive antenna **300a** is delayed by 15 μsec at bulk delay element **440.** The delayed signal is directed through power combiner **445,** where it is combined with the IF signal from the second uplink IF path. Delaying one IF uplink signal by 15 μsec will ensure that there is no destructive interference when the two signals are combined, since as earlier disclosed, the spacing of the receive antennas provides a time difference of approximately 8 nsec, and the delay between the two signals represents more than 4 bits of GSM data.

Since the omnidirectional receive antennas **300a** and **300b** are spaced at least 8 wavelengths apart, there is minimal co-

variance between them, and the multipath fades occur at different times on each antenna. When the single channel IF signals are combined at power combiner **445**, the stronger signal dominates. This dominance of the stronger signal will remain until the signal is received at the multichannel host BTS **340** for processing. At the multichannel host BTS **340**, adaptive delay equalization inherent in GSM Base Station processing removes up to 16 μsec of delay spread, so the combined diversity signals can be separated and demodulated as one signal at the multichannel host BTS **340**. Thus it can be seen that the delay combining technique of the present invention produces a combined diversity signal with a similar signal-to-noise ratio as a signal selected through a switched diversity selection method, yet without the requirement of switching hardware or careful slot-by-slot timing. To complete the uplink processing in the translator **310**, the composite signal from power combiner **445** is sent through a fast automatic level control (ALC) attenuator **450**.

Transmit bandpass filters **460** and **470** limit transmitted energy to the desired single channel range, after receiving the signal from amplifiers **455** and **465** respectively. At this point, uplink upconvert synthesizer **480** drives the mixer **475** by phase-locking to the common 10 MHz reference **505**. Uplink transmit bandpass filter **485** further limits transmitted energy to the desired RF frequency range, and power amplifier **490** provides the output signal to duplexer **500**. Detector **495** provides the energy output of power amplifier **490** back to the automatic level control circuit **450**. Duplexer **500** transmits the signal to directional transmit/receive antenna **320**, for transmission to multichannel host BTS **340**, where the signal is received by omnidirectional antenna **330**.

In the backhaul-to-mobile (downlink) direction, the signal is first received on the directional transmit/receive antenna **320** from the multichannel home base station and

forwarded to the duplexer **500**. In this direction only a single signal chain is needed, since Rayleigh fading is not experienced with transmissions between the fixed locations of the multichannel host BTS **340** and the translator **310**. The RF signal output provided by the duplexer **500** is passed to a first low noise amplifier **510**, receive bandpass filter **515**, and mixer **520**, which is driven by downlink downconvert synthesizer **525**, which is phase-locked to the common 10 MHz reference **505**. Mixer **520** converts the downlink signals to an intermediate frequency, and intermediate bandpass filter **530** provides the first limitation of the transmit frequency of the downlink IF signal. In a manner similar to the uplink path, intermediate frequency bandpass filters **540** and **550** limit transmitted energy to the desired single channel, after receiving the signal from amplifiers **535** and **545** respectively. Loopback tone detector **555** accepts as an input a coupled signal from the output of the IF band pass filter **550** in the downlink signal path. The loopback tone detector **555** controls the loopback circuitry **560**, which couples and mixes signals from the transmit path into the tow receive paths.

The output of the intermediate frequency bandpass filter **550** is forwarded to the automatic level control attenuator **570**, which feeds in sequence a RF mixer **575** and transmit bandpass filter **585** where the signal is up-converted back to the RF transmit band, being in the present embodiment 1930-1990 MHz. Downlink upconvert synthesizer **580**, like all synthesizers in the in-band translator **310**, is phase-locked to a common 10 MHz reference **505**. The output of transmit bandpass filter **585** is in turn fed to the power amplifier **590** prior to being fed to the transmit portion of the duplexer **405**, ultimately out to the antenna **300b**. ALC attenuator **570** is controlled based on the energy output of power amplifier **590**

measured by detector **565.**

Typically, class A/B linear amplifiers are used throughout the translator **310** in both the forward and reverse paths and the translator **310** is typically implemented with software programmable synthesizers so that the channel settings deployed may be easily selected during installation or when the system needs to be reconfigured.

The translator **310** is capable of receiving downlink signals at relatively low levels (-65 dBm to -95 dBm) and then retransmitting them with up to 141 dB of gain, at relatively high power levels (+46 dBm) over the mobile link with the automatic level control amplifier typically designed to control the transmitted forward path signal at a nominal 40 Watts.

In the reverse, or uplink path, that is from the mobile to the backhaul link, the translator **310** is designed to receive a low-level mobile signal (-25 dBm to -110 dBm) from its omni-directional antennas **300a**, **300b** and to retransmit to the base transceiver system 340 with up to approximately 115 dB of signal gain with power of as high as 1 Watt (+30 dB) over the directional antenna **320**.

As a result, two combined reverse mobile transmit diversity channels are continuously transmitted back to the base transceiver system with a 15 microsecond delay between them. This delay combining diversity takes advantage of the adaptive delay equalization inherent in GSM base stations, and allows coherent diversity summation to take place, after digital demodulation within the home base station. This is as effective as delay switching at the site of the translators, and requires significantly less hardware. The net effect is that, even with a deployment of these "range extending" translators **310**, the received signal performance expected is as effective against multi-path fading and noise as deploying a standard base transceiver system in each of the remote translator sites.

While we have shown and described several embodiments in

accordance with the present invention, it is to be understood that the invention is not limited thereto, but is susceptible to numerous changes and modifications as known to a person skilled in the art, and we therefore do not wish to be limited to the details shown and described herein, but intend to cover all such changes and modifications as are obvious to one of ordinary skill in the art.

CLAIMS

What is claimed is:

1. In a wireless telecommunication system consisting of a plurality of cells, the plurality of cells being located substantially adjacent to one another, and the cellular communication system operating over a specified frequency range, the wireless telecommunication system making use of a frequency allocation plan that arranges the cells into clusters wherein only one of said cells within said cluster contains a broadband base transceiver station, the cellular communication system comprising:

   an in-band translator apparatus located in each of said cluster of cells not containing said broadband base transceiver station, wherein said in-band translator apparatus employs uplink delay combining for receive diversity.

2. A wireless telecommunication system as in claim 1, wherein said wireless communication system is a GSM-based system.

3. A wireless telecommunication system as in claim 2, wherein said GSM-based system is one of GSM-900, GSM-1800, and GSM-1900.

4. A wireless telecommunication system as in claim 1, wherein said in-band translator communicates with said broadband transceiver station via a wireless backhaul link, said system further comprising:

   means for maintaining said receive diversity over said backhaul link.

5. In a wireless telecommunication system consisting of a plurality of cells, the plurality of cells being located substantially adjacent to one another, and the cellular

communication system operating over a specified frequency range, the wireless communication system making use of a frequency allocation plan that arranges the cells into clusters wherein only one of said cells within said cluster contains a broadband base transceiver station, a method of providing wireless communication with a plurality of mobile stations comprising:

receiving a first signal from at least one of said plurality of mobile stations;
receiving a second spatially diverse signal from said at least one of said plurality of mobile stations;
delaying one of said received signals;
combining said signals; and
transmitting said combined signal to said broadband base transceiver station.

6. The method of providing wireless communication with a plurality of mobile stations in accordance with claim 5, wherein:

said second spatially diverse signal is received at least 8 wavelengths apart from said first received signal.

7. The method of providing wireless communication with a plurality of mobile stations in accordance with claim 5, wherein:

the interval for delaying said one of said received signals is up to 16 μsec.

8. The method of providing wireless communication with a plurality of mobile stations in accordance with claim 5, wherein said in-band translator communicates with said broadband transceiver station via a wireless backhaul

link, said method further comprising the step of:

maintaining said receive diversity over said backhaul link.

9. In a wireless telecommunication system consisting of a plurality of cells, the plurality of cells being located substantially adjacent to one another, and the cellular communication system operating over a specified frequency range, the wireless telecommunication system making use of a frequency allocation plan that arranges the cells into clusters wherein only one of said cells within said cluster contains a broadband base transceiver station, the cellular communication system comprising:

an in-band translator apparatus located in each of said cluster of cells not containing said broadband base transceiver station, said inband translator further comprising:

first antenna means for receiving a first signal from at least one of a plurality of mobile units;

second antenna means for receiving a second signal from said at least one of a plurality of mobile units;

delay means for delaying said second signal;

combining means for combining said first signal and said delayed second signal;

third antenna means for transmitting said combined signal to said broadband base transceiver station.

10. A wireless telecommunication system as in claim 9, wherein said wireless communication system is a GSM-based system.

11. A wireless telecommunication system as in claim 9, wherein said wireless communication system is one of GSM-

900, GSM-1800, and GSM-1900.

12. A wireless telecommunication system as in claim 9, wherein the interval for delaying said second signal is up to 16 μsec.

13. A wireless telecommunication system as in claim 9, wherein said at least one of a plurality of mobile units is located in the cell containing said in-band translator.

14. A wireless telecommunication system as in claim 9, wherein said at least one of a plurality of mobile units is located in one of said plurality of cells adjacent to said one of said plurality of cells containing said in-band translator.

15. A wireless telecommunication system as in claim 9, wherein said first antenna means is separated from said second antenna means by at least 8 wavelengths.

16. A wireless telecommunication system as in claim 9, wherein said in-band translator communicates with said broadband transceiver station via a wireless backhaul link, said method further comprising the step of:

maintaining said receive diversity over said backhaul link in said signal transmitted from said third antenna means.

17. A wireless telecommunication system as in claim 16, wherein said wireless backhaul link communications use the same frequency band as said first and second signals.

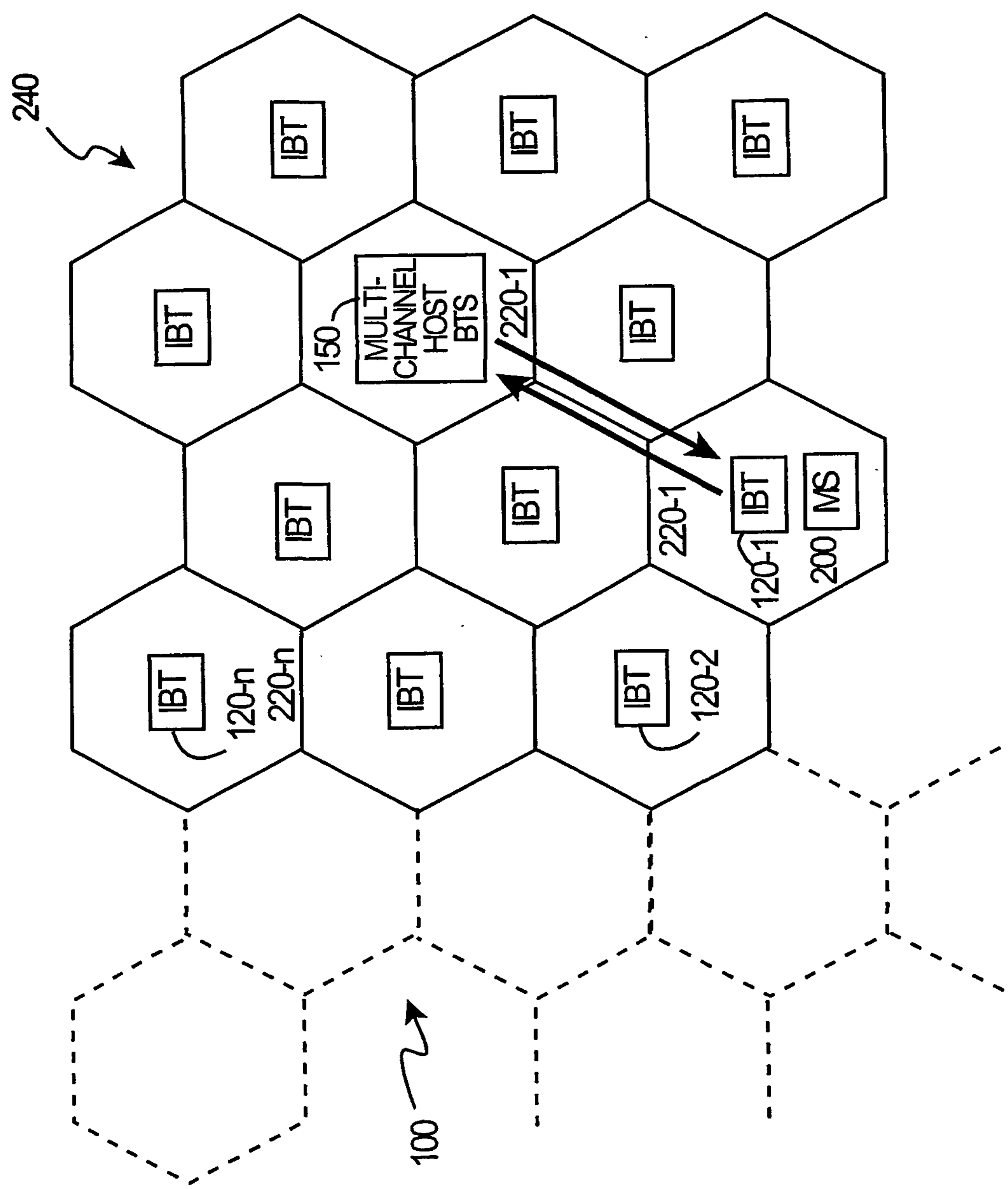
240
IBT
IBT
IBT
IBT
150
MULTI-CHANNEL HOST BTS
220-1
IBT
IBT
IBT
220-1
IBT
MS
120-1
200
IBT
120-n
220-n
IBT
IBT
120-2
100

FIG. 1

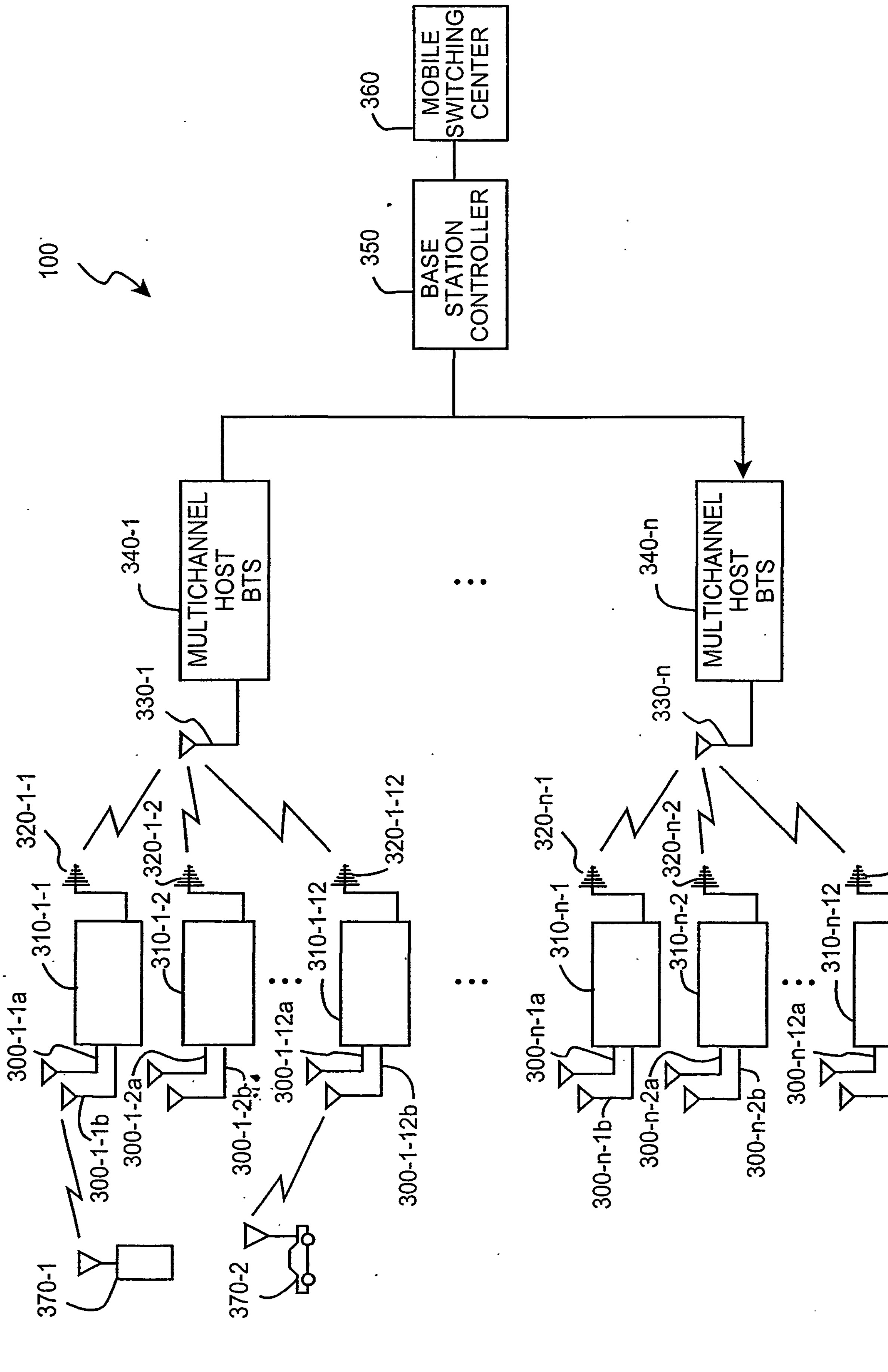
100
MOBILE SWITCHING CENTER
360
BASE STATION CONTROLLER
350
MULTICHANNEL HOST BTS
340-1
MULTICHANNEL HOST BTS
340-n
330-1
330-n
320-1-1
320-1-2
320-1-12
320-n-1
320-n-2
320-n-12
310-1-1
310-1-2
310-1-12
310-n-1
310-n-2
310-n-12
300-1-1a
300-1-1b
300-1-2a
300-1-2b
300-1-12a
300-1-12b
300-n-1a
300-n-1b
300-n-2a
300-n-2b
300-n-12a
300-n-12b
370-1
370-2

FIG. 2

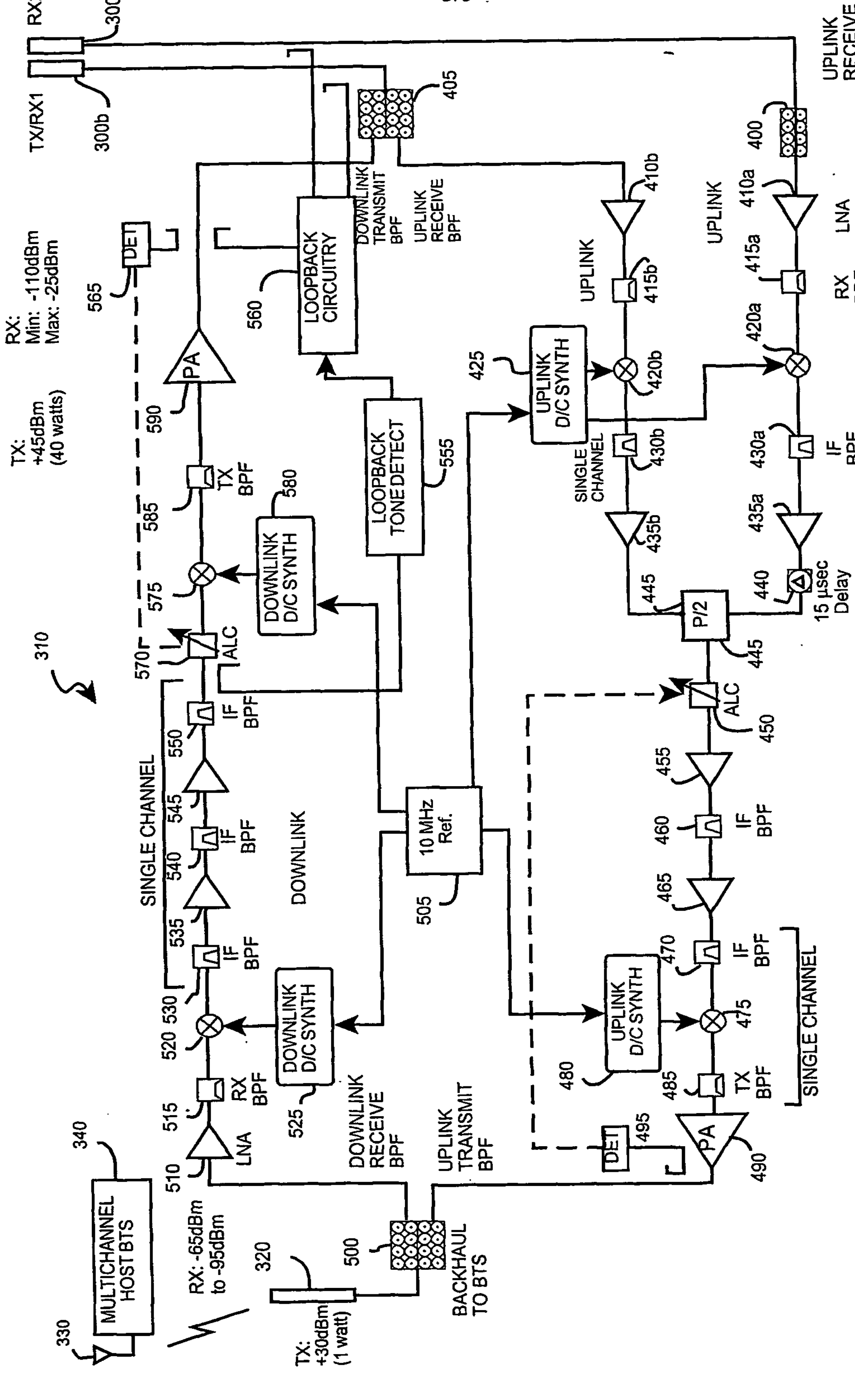
RX2
300a
TX/RX1
300b
405
400
UPLINK RECEIVE BPF
RX:
Min: -110dBm
Max: -25dBm
TX:
+45dBm
(40 watts)
565
DET
PA
590
LOOPBACK CIRCUITRY
560
DOWNLINK TRANSMIT BPF
UPLINK RECEIVE BPF
410b
410a
LNA
UPLINK
415b
415a
RX BPF
420a
420b
425
UPLINK D/C SYNTH
LOOPBACK TONE DETECT
555
TX BPF
585
DOWNLINK D/C SYNTH
580
SINGLE CHANNEL
430b
430a
IF BPF
435b
435a
440
15 µsec Delay
445
P/2
575
310
570
ALC
450
IF BPF
550
545
540
535
SINGLE CHANNEL
DOWNLINK
10 MHz Ref.
505
455
460
465
470
UPLINK D/C SYNTH
475
480
485
495
490
SINGLE CHANNEL
520 530
DOWNLINK D/C SYNTH
525
515
510
DOWNLINK RECEIVE BPF
UPLINK TRANSMIT BPF
340
MULTICHANNEL HOST BTS
330
RX: -65dBm to -95dBm
320
500
TX: +30dBm (1 watt)
BACKHAUL TO BTS

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/09684

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H04B 7/15
US CL :455/ 11.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/ 11.1, 524, 101-103, 272-273, 276.1; 375/267, 299, 347;370/280, 294, 315, 321, 337, 347.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,649,292 A (DONER) 15 JULY 1997, SEE FIGS. 1-2.	1-17
A	US 5,592,480 A (CARNEY ET AL) 07 JANUARY 1997, SEE FIGS. 1-9.	1-17
A	US 5,544,171 A (GODECKER) 06 AUGUST 1996, SEE FIGS. 1A-1B.	1-17
A	US 5,152,002 A (LESLIE ET AL) 29 SEPTEMBER 1992, SEE FIGS. 1-6.	1-17
A	US 5,127,025 A (OKANOUE) 30 JUNE 1992, SEE FIGS. 1-7.	1-17
A	US 5,924,022 A (BEASLEY ET AL) 13 JULY 1999, SEE FIGS. 1-10.	1-17

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* *Special categories of cited documents:*

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 05 JUNE 2000	Date of mailing of the international search report 05 JUL 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer D. TO Telephone No. (703) 305-4827

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/09684

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,615,215 A (UTTING ET AL) 25 MARCH 1997, SEE FIGS. 1-10.	1-17
A	US 5,542,107 A (KAY) 30 JULY 1996, SEE FIGS. 1 AND 5.	1-17
A	US 5,940,445 A (KAMIN, JR.) 17 AUGUST 1999, SEE FIGS. 2-4.	1-17
A	US 5,926,470 A (TIEDEMANN, JR.) 20 JULY 1999, SEE FIG. 13.	1-17